The IFMIF Target Facility Engineering Design and the Validation of Key Issues within the IFMIF/EVEDA Project

4th High Power Targetry Workshop
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On behalf of the IFMIF-EVEDA Project Team

Outline of talk

- Scope of IFMIF and of the IFMIF/EVEDA Project
- IFMIF Loop Concept and ELiTe Loop for off-beam tests
- Li Target Assemblies and validation of free surface flow
  - Functionality and performance
  - Manufacturability
  - Operability
  - Safety
  - Low Waste
  - Costs
- Li safety issues for IFMIF and ELiTe
- Summary and conclusions

Acknowledgment:

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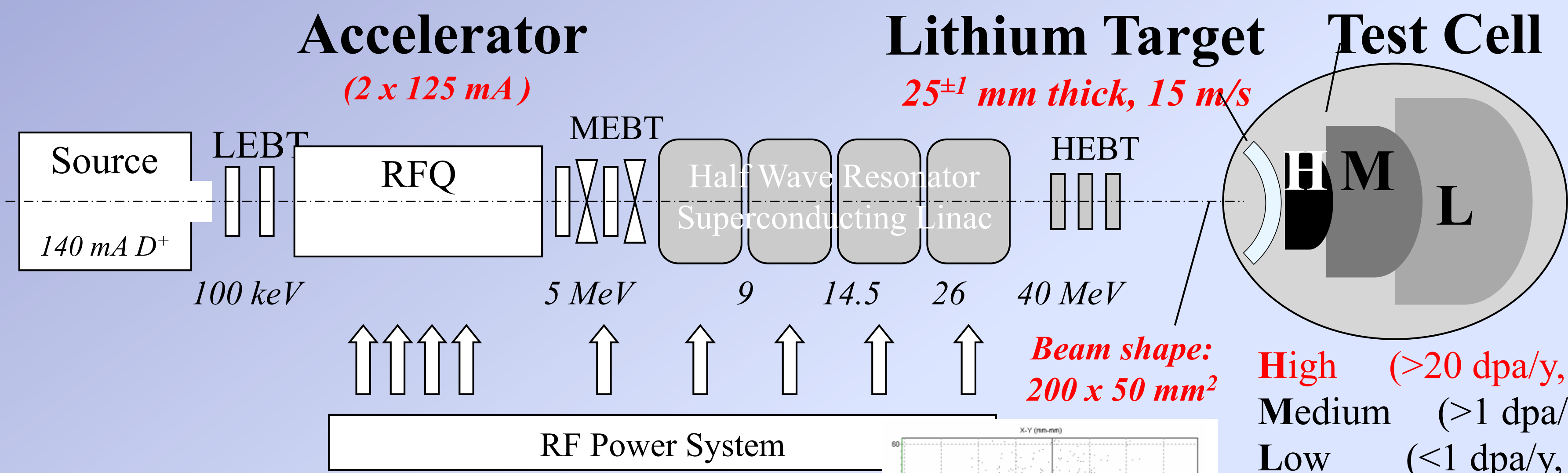
Mitsubishi Heavy Industry-Mechatronic Systems

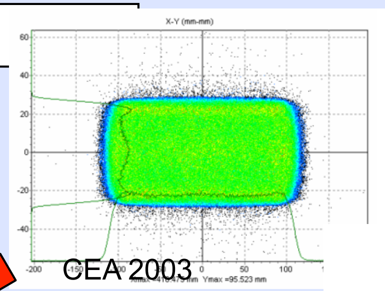
Design principles

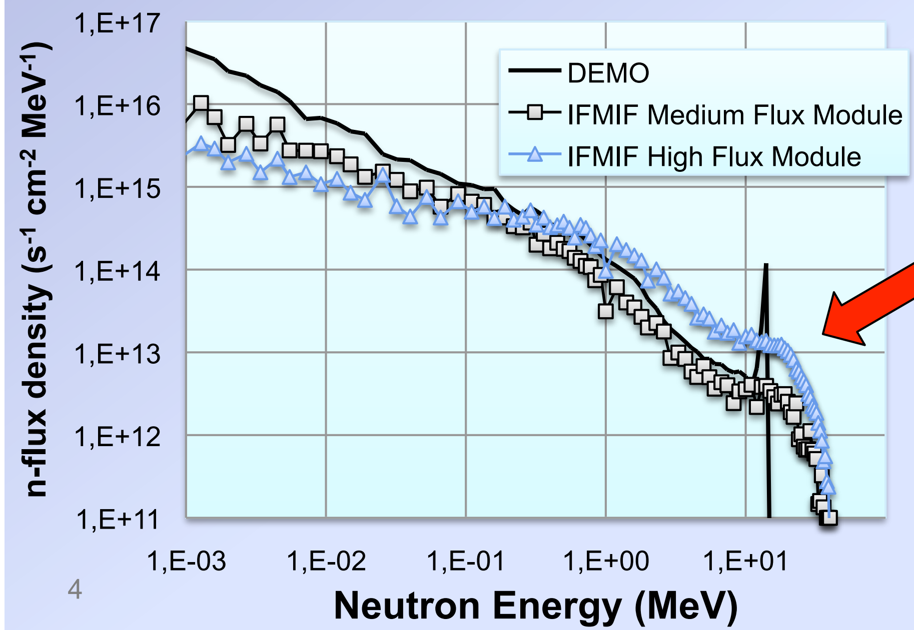
- Functionality and performance
- Manufacturability
- Operability
- Safety
- Low Waste
- Costs

Principle of IFMIF



High (>20 dpa/y, 0.5 L)
Medium (>1 dpa/y, 6 L)
Low (<1 dpa/y, > 8 L)



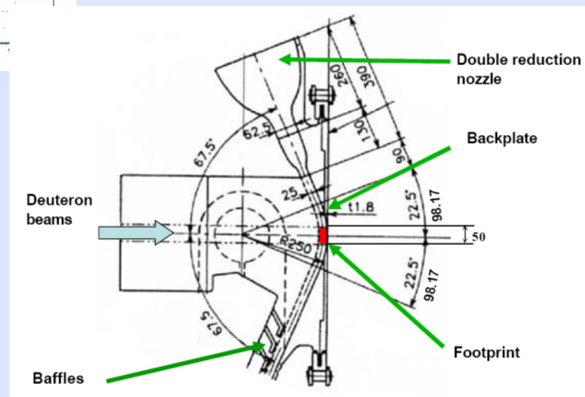


Typical reactions

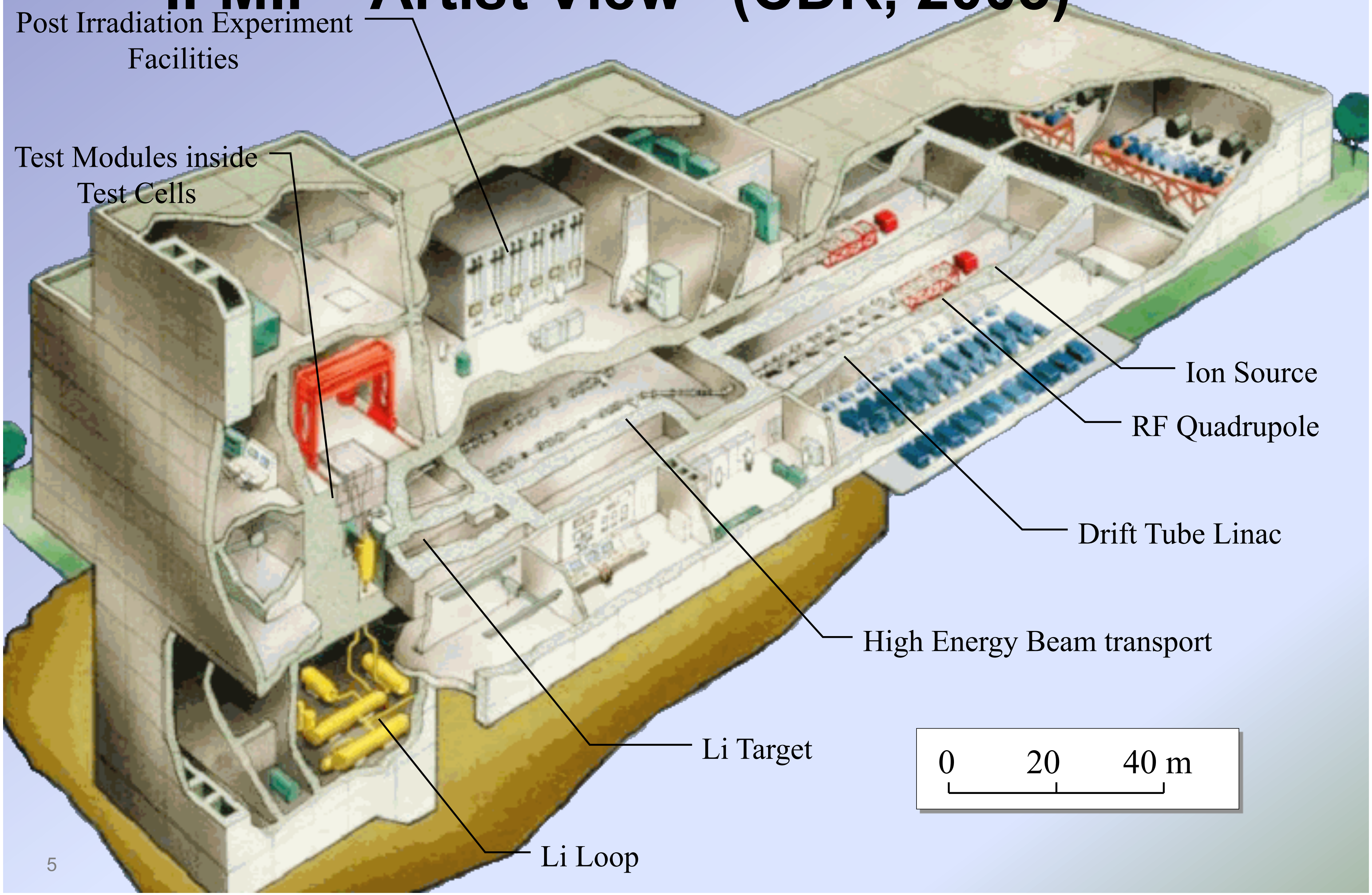
$^{7}Li(d,2n)^{7}Be$

$^{6}Li(d,n)^{7}Be$

$^{6}Li(n,T)^{4}He$



IFMIF "Artist View" (CDR, 2003)

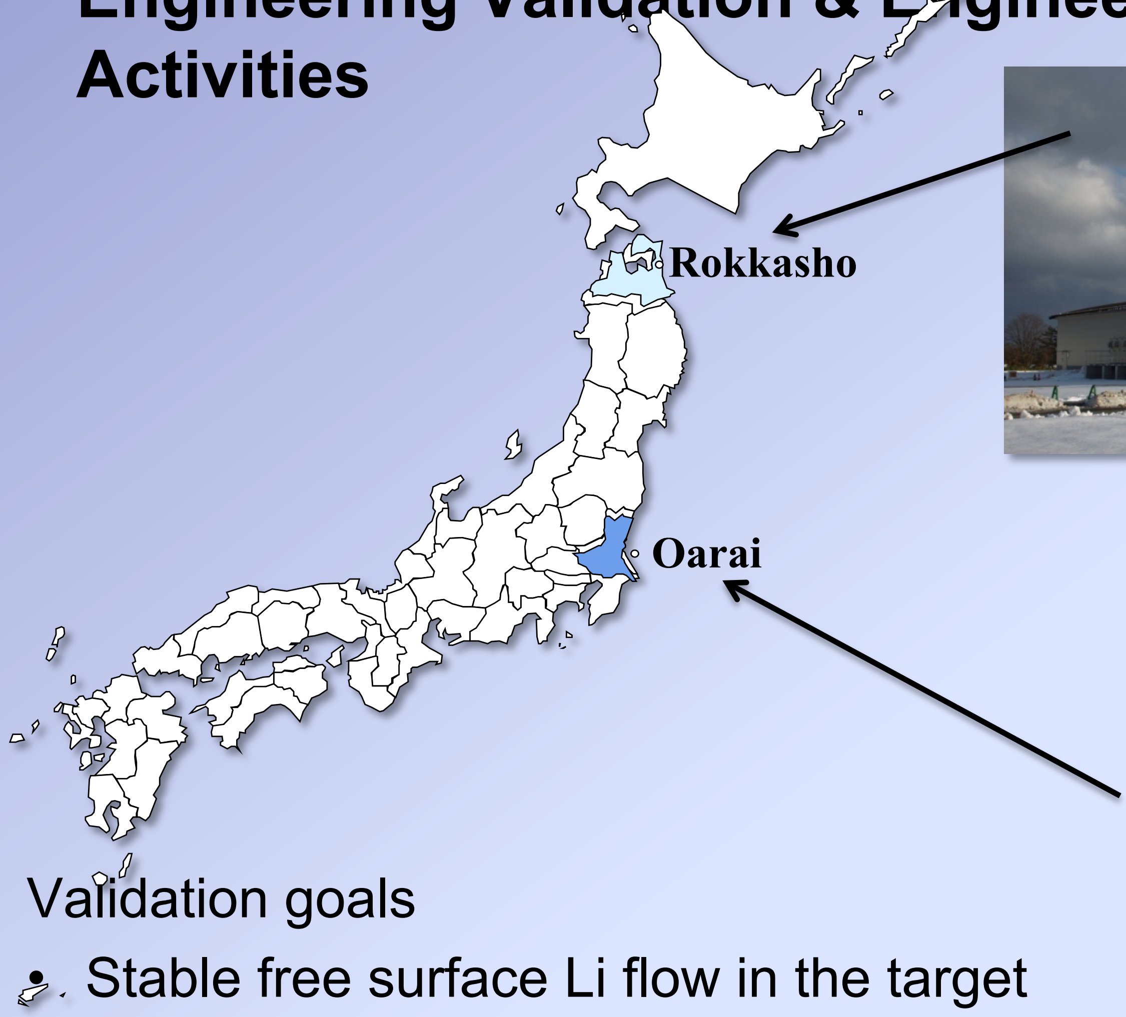


Objectives of the IFMIF/EVEDA Project

- Produce a detailed, complete and fully integrated engineering design of the International Fusion Materials Irradiation Facility and all data necessary for future decisions on the construction, operation, exploitation and decommissioning of IFMIF
- Validate continuous and stable operation of each IFMIF subsystem by designing, manufacturing and testing scalable models to ensure engineering feasibility

Article 1 of Annex 1 of BA Agreement, February 2007

Engineering Validation & Engineering Design Activities



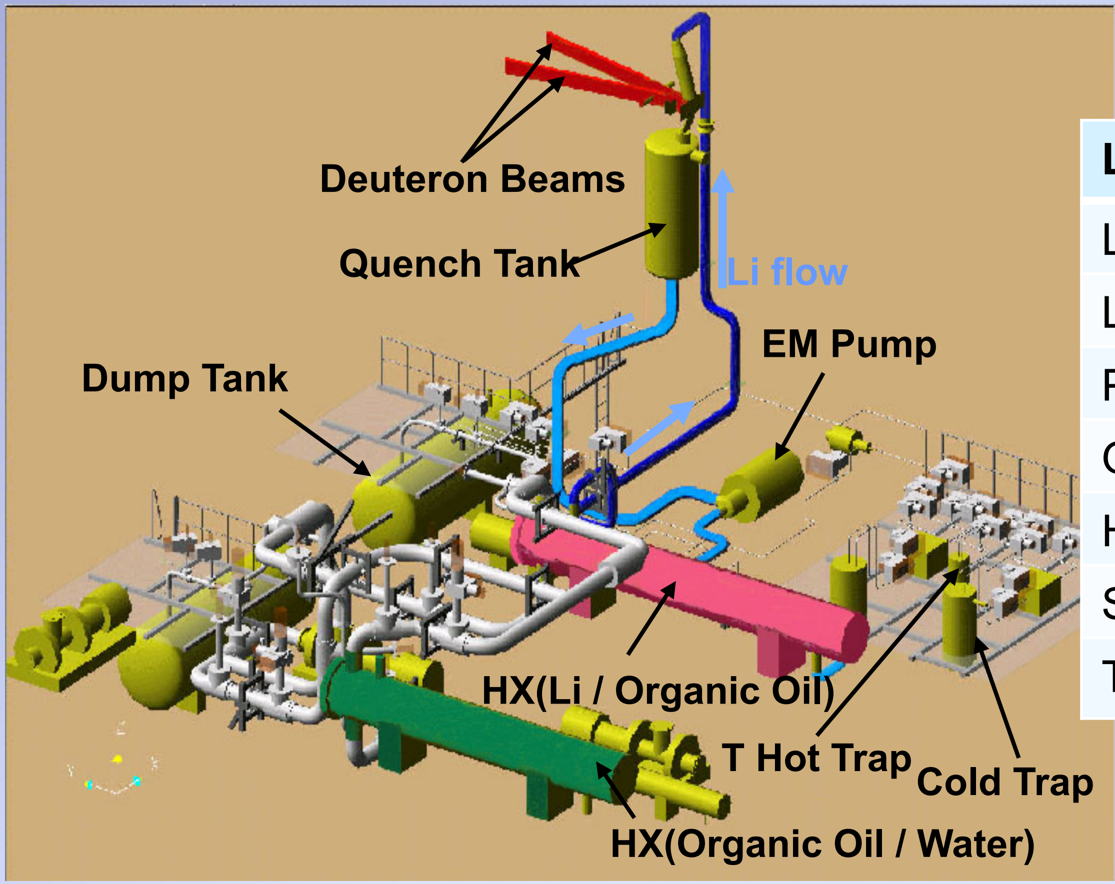

IFMIF/EVEDA Accelerator Building


Lithium Test Loop
(scale 1/3)

Validation goals

- Stable free surface Li flow in the target assembly
- Achievement of low impurity levels of oxygen, nitrogen, hydrogen (< 10 wppm)

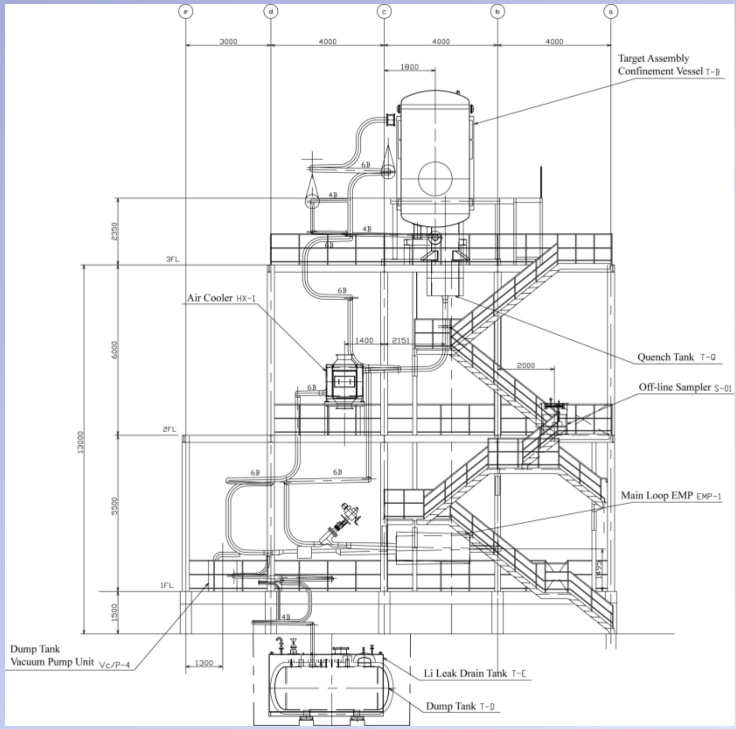
IFMIF Li loop baseline concept (2003)

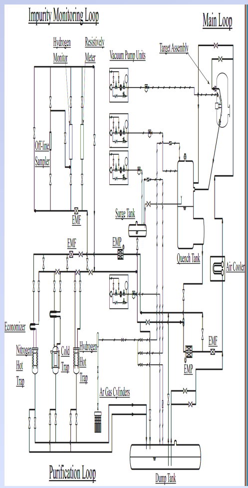


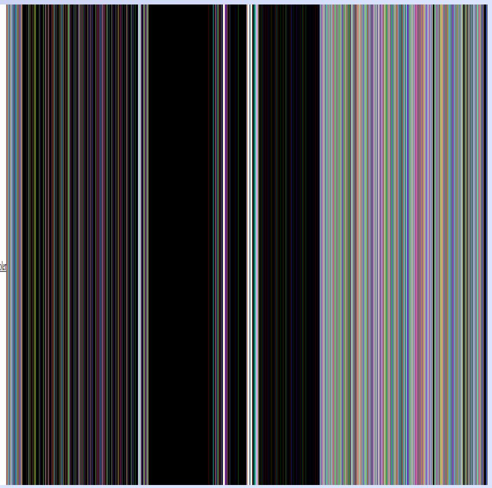
Loop properties	
Li inventory	4.5 to
Li flow rate	130 l/s
Piping	8/10“
Operating temperature	250-350ºC
Heat to be removed	10 MW
Secondary cooling	oil
Tertiary cooling	water

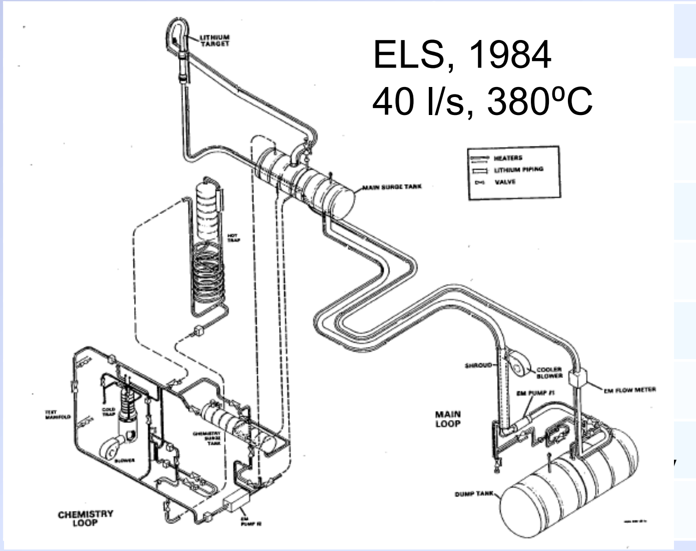
Structural design code not yet decided
RCC-MX or equivalent Japanese code for safety boundary

ELiTe loop design/layout









Major differences to IFMIF

- Scaling in flow rate 1:2.6
- NPSH requires similar height as IFMIF
- Air cooler, no secondary loops
- Bypass branch for target assembly to facilitate start of flow through target assembly
- Purification system integrated in main structure
- Purification branch with small EMP (10 l/s)

Design conditions:

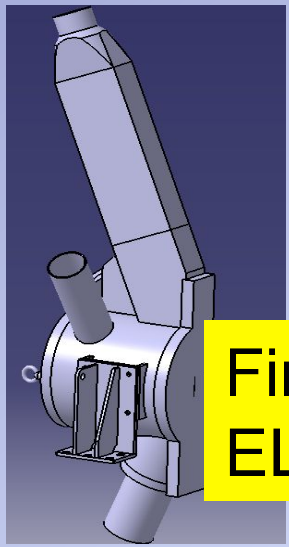
- Materials and testing according to JIS standards
- Structural design and permissible stresses according to Japan Pressure Vessel and Piping Structural Standards,(JSME)
- Classification according to Japan Electric Association (JEAC/ JEAG)
- Fire Service Law and Service Act

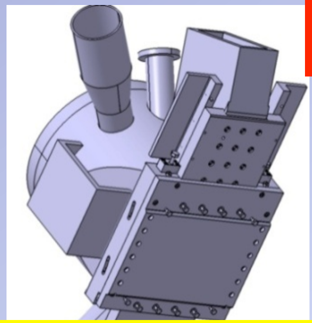
Licensed by Mayor of Oarai-Town

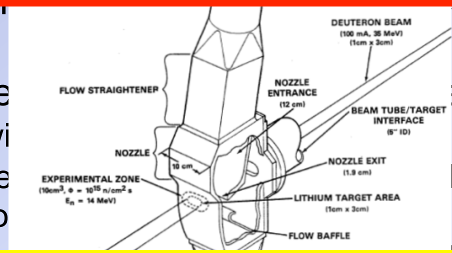
Target assembly concepts

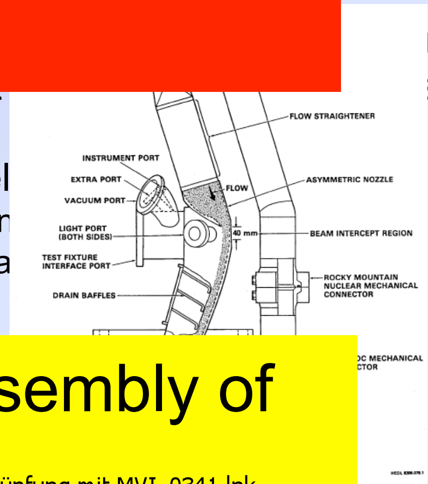
Waste reduction
→ Replaceable backwall

rm a
shaped
open
Three
• TA wi
• Lipse
• Bayo



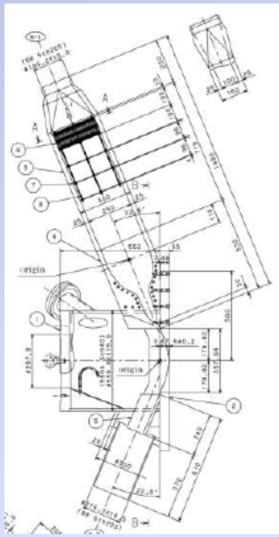


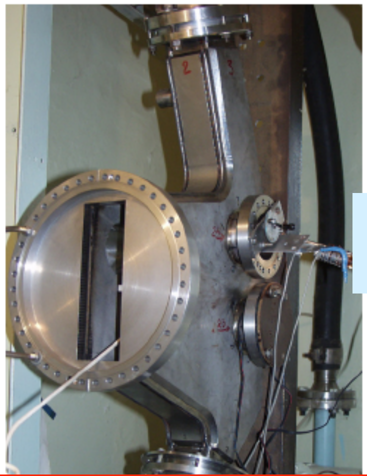




First flow through integral target assembly of ELiTe loop, 7 m/s

Verknüpfung mit MVI_0325.lnk
Verknüpfung mit MVI_0341.lnk





Li jet width	**100 mm**
Li jet height	**25±1 mm**
Flow channel	**250 mm → 7 m**
Flow veolcity	**10-20 m/s**
Nozzle	
Nozzle reducti	
Nozzle and cha	**< 3 μm**
Vacuum pressu	**10^{-4} to 10^{-3} Pa**
Argon pressur	**< 0.1 Mpa(a)**

ISTC 2603, 2006
Li jet 70 mm wide, 10 mm thick

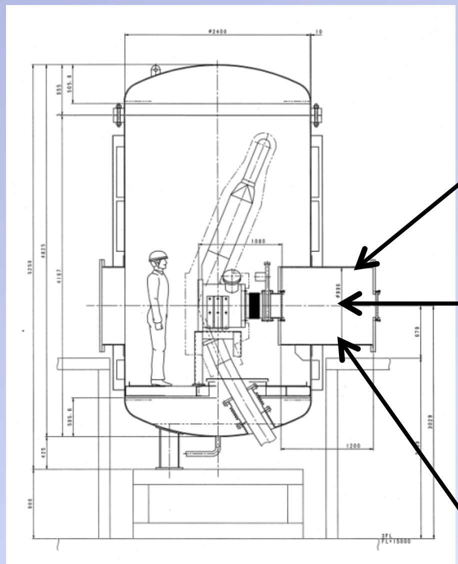
Power deposition 1 GW/m^2
→ Windowless liquid metal cross flow

Li free surface flow validation

- How to assure stable Li free surface flow in the beam footprint; i.e. thickness variation < ±1 mm
- How to manage Li evaporation from the free surface

High Speed Video of Li Flow in Osaka Loop; courtesy H. Horiike

Verknüpfung mit port1_hsv_f50.lnk

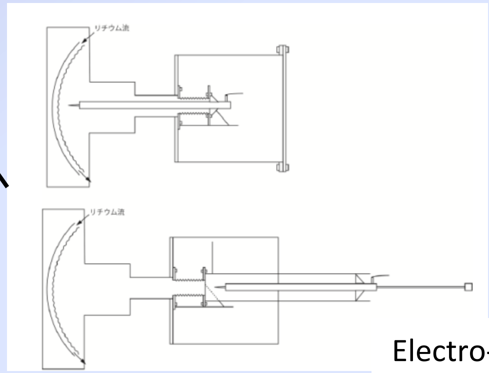


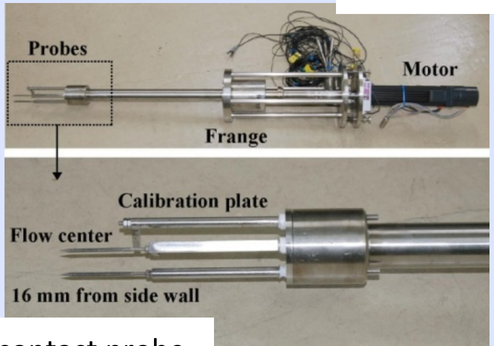
Stereo-Scopic Imaging System

HSV

Li deposition sampler

Quartz microbalance

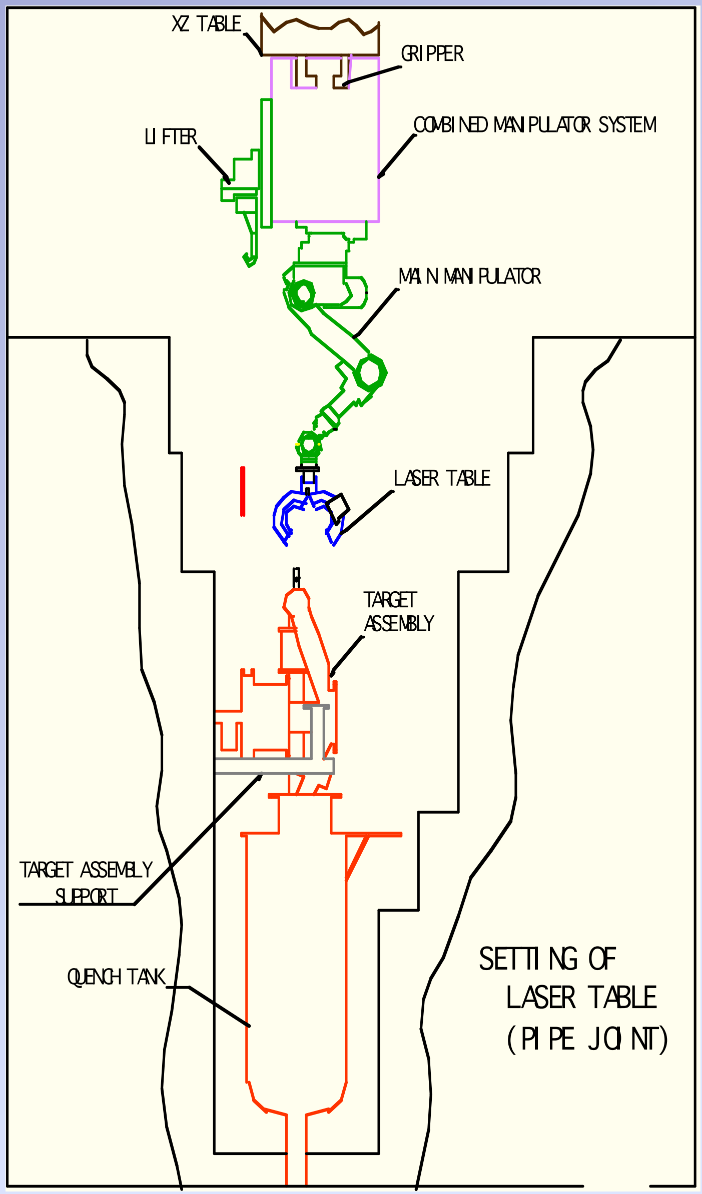




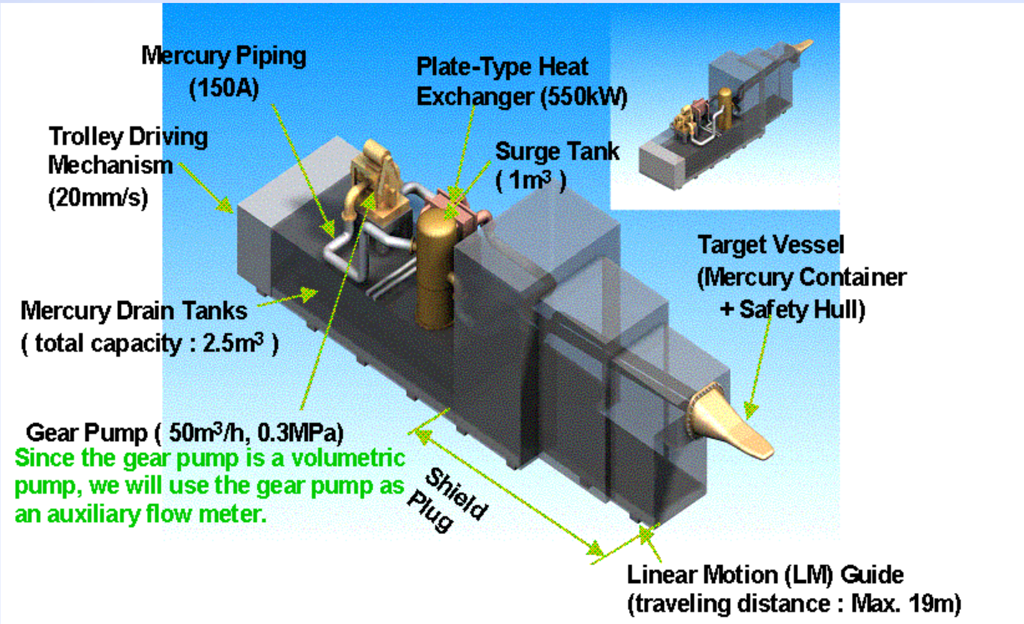
Electro-contact probe

Diagnostics developed by Osaka University and qualified in Osaka loop
CFD modeling by several institutes

Operability and Maintenance



Insert from top or Trolley?



Lithium Purification in IFMIF and Validation

Lithium has to be purified

- *To maintain the liquid metal properties (viscosity, avoid plugging)*
- *To mitigate corrosion/erosion. Nitrogen enhances corrosion in stainless steels by forming a soluble CrLiN-compound*
- *To reduce the radioactive inventory and the limit the radiation field around the loop. Production of ^{3}H is about 7.5 g/fpy and of ^{7}Be is about 1.5 g/fpy in IFMIF. Corrosion products from the target assembly and others passing through the target assembly are activated*

Purification system

- *Cold trap operating below the loop temperature*
- *Nitrogen hot trap operating at 580-600ºC*
- *Hydrogen isotopes trap operating at 280-300ºC*
- *On-line composition monitors (hydrogen, resistivity, plugging meter)*
- *Li samplers for off-line analysis*

Target impurity level design values

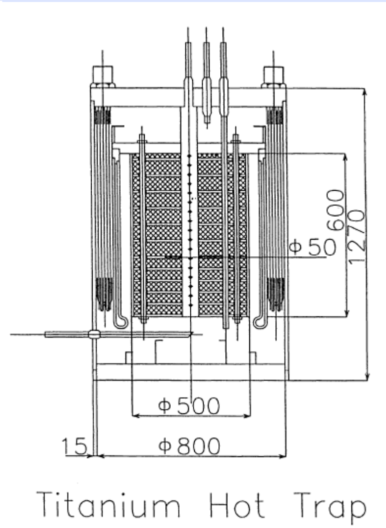
- *10 wppm for H, N and corrosion products*
- *1 wppm for ^{3}H*

IFMIF nitrogen trap and ELiTe validation

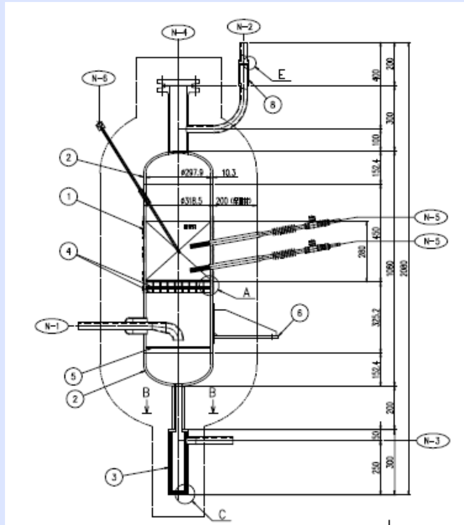
- IFMIF reference design uses Ti sponge getter
- University of Tokyo develops Fe-Ti getter with 5-10 at.-% Ti to overcome saturation due to formation of TiN layer on pure Ti
- Qualification of getter material on laboratory scale by UoT (in stagnant vessel and in small 1 l Li loop)
- Main source term is
  - *Initial Li impurity*
  - *Surface coverage* … *sumption as for O*
  - *Recondamination of surfaces and Li during maintenance*

Challenges
- Design temperature of 600ºC
- Preheater and economizer

Properties	IFMIF ref	ELiTe
Getter	Ti sponge	Fe-5% Ti pebbles 0.16 mm diam.
Operating temp.	580-600ºC	
Getter mass	230 kg	95 kg
Capacity for nitrogen	45 kg (30% margin)	4.2 kg
Li flow rate		10 l/min
Residence time		10 min



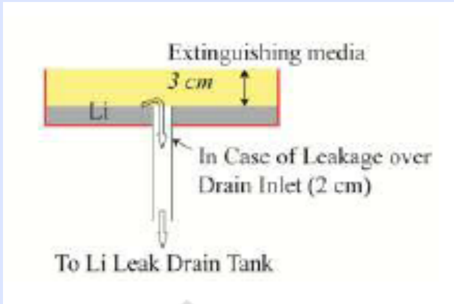
IFMIF



ELiTe

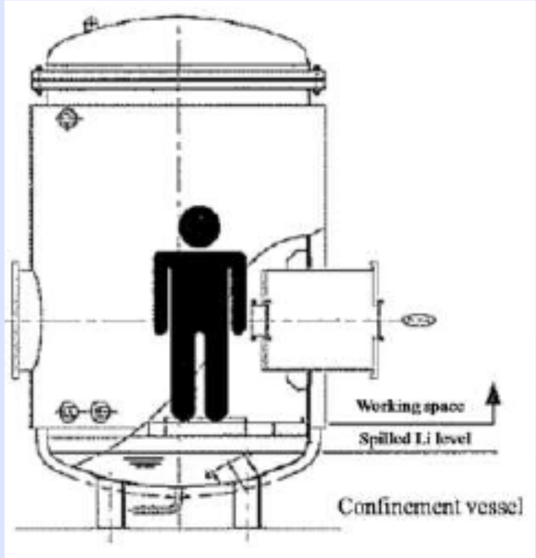
ELiTe safety measures to control spill and fire

- ELiTe loop safety approach is based on the rules established for operation of large Na loops in the JAEA Na lab at Oarai
  - *Rules have been extended to Li operation, but specifity of Li needs to be considered (e.g. reactivity, operating temperature range, weight and specific heat, toxicity, etc.)*
  - *Safety measures have been widely copied in order to facilitate licensing*
- Detection and control of spills by
  - *Leak detection wires placed along the piping an all welds placed in the surfaces below the thermal insulation*
  - *Leak detectors on valve stems*
  - *Segmented catch pans (5 m^2) with drain pipes to a storage vessel*
  - *Video-sureillance of platform*
  - *Emergency draining of loop*



ELiTe safety measures to control spill and fire

- Detection and control of fires
  - *Smoke detectors*
  - *Ar flooding of air ducts and vessels*
  - *Human intervention to extinguish fires with specific agent NATREX-L (protective clothing and independent air supply)*
- Containement vessel for target assembly
  - *Operation under Ar atmosphere*
- The loop itself is exposed to air
  - Li fire in case of spills can thus not be excluded
  - Assessment of possible leakages based on accident scenarios



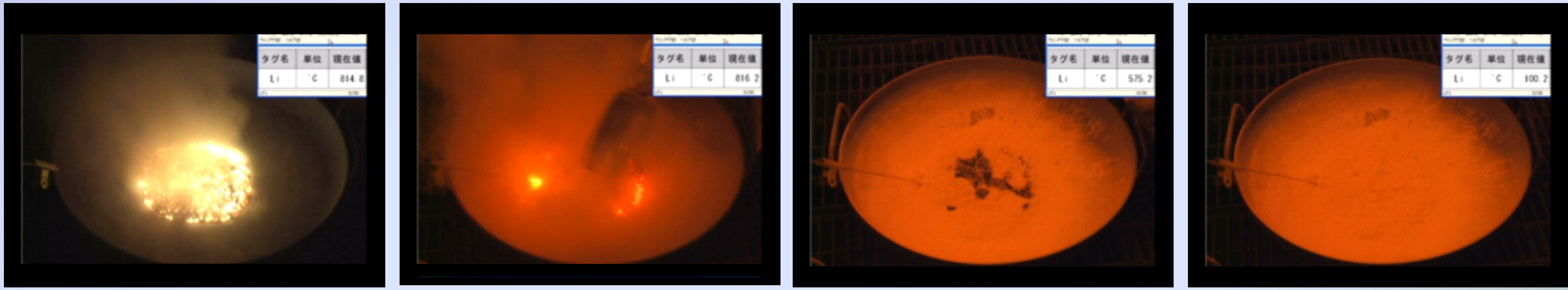
Qualification of fire extinguishant

- Selection of Natrex-L (mostly NaCl)
- Coverage with several cm of extinguishant is required to suppress flames and cause drop of pool temperature

The fire-extinguishing behavior of dry sand applied to lithium

(a) Before application (b) Just after application (c) End of combustion (d) After fire extinguishing

The fire-extinguishing behavior of lithium by application of Natrex-L



(a) Before application (b) Just after application (c) End of combustion (d) After fire extinguishing

Courtesy
T. Furukawa, JAEA

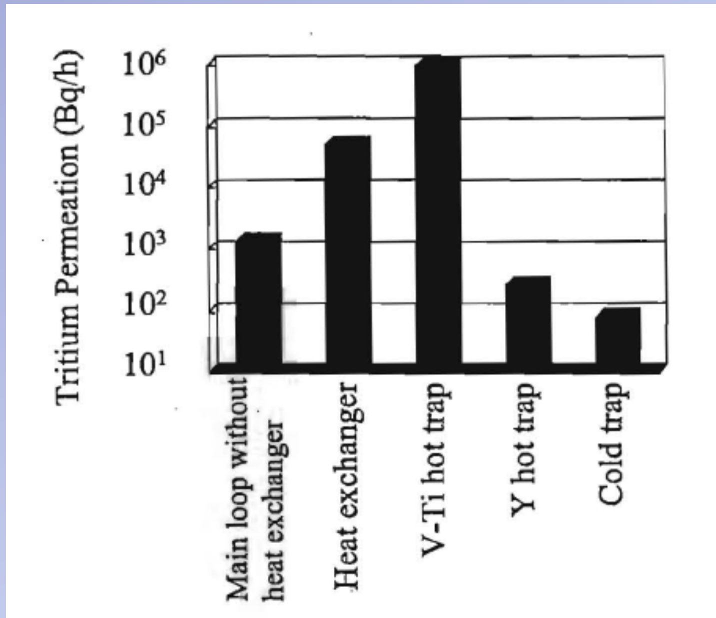
Lithium Handling

IFMIF safety measures

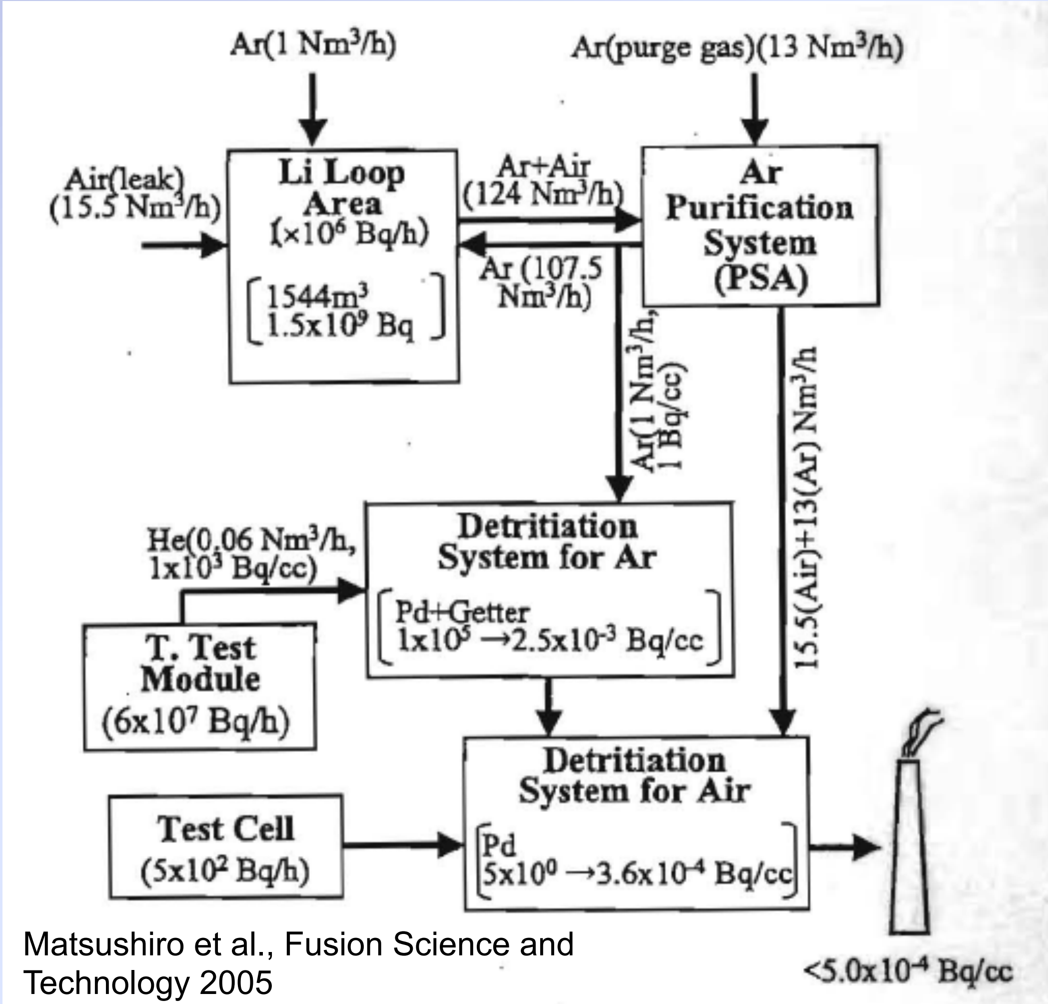
- The main requirement for IFMIF is to safely contain the radioactive inventory and do not exceed the legal release limits under normal or any accident situation
- Additional measures are therefore required
- The rooms (about 1500 m^3) containing the Li loop are conceived as a containment, flooded with Ar and kept under a pressure slightly lower than the surrounding rooms
- The Ar is conditioned such that a fire cannot develop in case of a leak (minimum air content, low humidity)
- The Ar atmosphere needs to be conditioned, since
  - *Air ingress cannot be excluded*
  - *Tritium diffuses through the loop piping (about 1 MBq/h)*

→ Recycling of Ar after extraction of the air and of the tritium

IFMIF safety measures



Tritium permeation from Loop



Matsushiro et al., Fusion Science and Technology 2005

Detriation System Flow Chart

Summary and conclusions

- The Li test loop has been constructed and commissioned
- Validation tests are scheduled to start in autumn
- The proof of principle that stable flow and low impurity levels can be achieved would be an important step forward, but many other issues which may affect operability, performance and costs still have to be resolved until construction
- Engineering design of the IFMIF Li facility is about to start now with quite some delay
- Baseline concept is defined, but some key issues are still open
- We risk to run out of time in the project, which needs to be completed by 2013